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by
S.J. Kristof
and
M.F. Baumgardner

The Laboratory for Applications of Remote Sensing

Purdue University
West Lafayette, Indiana

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S. J. Kristof[2]

and

M. F. Baumgardner[3]

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[2]Research Agronomist, Laboratory for Applications of Remote Sensing, Purdue University, West Lafayette, Indiana

[3]Associate Professor of Agronomy and Leader of Earth Sciences Research Programs, Laboratory for Applications of Remote Sensing, Purdue University, West Lafayette, Indiana.

ABSTRACT

Multispectral data and automatic data processing were used to map surface soils patterns and to follow the changes in multispectral radiation from a field of maize (Zea mays) during a period from seeding to maturity.

The test area consisted of 40 hectares located in Tippecanoe County, Indiana and was seeded to maize in mid-May 1970.

Panchromatic aerial photography was obtained in early May 1970 and multispectral scanner missions were flown on May 6, June 30, August 11 and September 5, 1970 to obtain energy measurements in 13 wavelength bands.

The orange portion of the visible spectrum was used in analyzing the May and June data to cluster relative radiance of the soils into eight different radiance levels. The reflective infrared spectral band was used in analyzing the August and September data to cluster maize into different spectral categories. The computer was trained with the clusters to recognize specific surface feature categories and to classify all data within the test area.

The computer-produced soil patterns had a striking similarity to the soil pattern of the aerial photograph. These patterns became less distinct as the maize canopy

increased. The reflective infrared categories also indicated areas where the maize deteriorated more rapidly due to an infection of corn blight or to a nutrient deficiency.

INTRODUCTION

Dramatic advances have been made in recent years in the measurement of radiant energy to identify and characterize earth surface features. A wide variety of instruments has been employed to measure reflected and emitted energy from targets or subjects of interest. Computer-implemented pattern recognition techniques are being used in the analysis of multispectral data obtained rapidly over large areas. One of the important potential applications of these techniques is in the rapid inventory and assessment of soils resources and land use.

The purpose of this paper is to present the results of research using multispectral data and automatic data processing (ADP) to map surface soils patterns and to follow the changes in multispectral radiation from a field of maize (Zea mays) during a period from seeding to maturity.

According to Gates (5,6) the spectral quality and intensity of reflectance and emittance from a vegetated scene depend upon the soil and the geometry, morphology, chemistry, and physiology of the green plant. As any of these soils and plant variables change, the quality and quantity of radiation from a scene will be affected.

The impact of radiant energy on plants and soils can be measured under field conditions in different ways and with different spectral instruments. Krinov (13) worked in the field with spectrographs mounted on tripods and with a spectrograph mounted in an aircraft. Olson (15) made field spectral measurements with a mobile (enclosed trailer) Beckman DK-2A spectroreflectometer. Cipra et al. (1) recorded spectral measurements of different soils with an Exotech Model 20 spectroradiometer. Holmes (9), describing techniques of spectroscopy, suggested a field spectroscope with a relatively small field of view capable of scanning subjects of interest with a rotating mirror in a rectangular, television-like raster. The input in various spectral bands are detected simultaneously and recorded in parallel on magnetic tape.

In recent years an airborne multispectral scanning system, constructed at the Institute of Science and Technology, University of Michigan, has been used by the Laboratory for Applications of Remote Sensing (LARS) to obtain electromagnetic radiation data from many field experimental areas. This scanner operates in the spectral range from 0.35 to 15 micrometers. The energy responses of the

various wavelength bands are obtained in a series of continuous scan lines recorded on magnetic tape. Details of this technique have been described in numerous papers (4,11,16,17,18).

MATERIALS AND METHODS

For this study a test area of 40 hectares was selected. Known as Soil Test Area 5 (STA 5), this field is located in Tippecanoe County, Indiana in a transition zone between soils developed under deciduous hardwood forests and those developed under prairie vegetation (Figure 1). Soil patterns of the field are typical of the area (Figure 2). The field was seeded to maize in mid-May 1970. Rate of fertilizer application was 45 kg per hectare of 9-23-30, applied in the row.

Multispectral scanner missions were flown on May 6, June 30, and September 5, 1970 at an altitude of 915 m and on August 11, 1970 at 1520 m (Table 1). Prior to seeding, 1-kg surface soil samples were obtained on a grid pattern at intervals of 46 m. Chemical and mechanical analyses were made on 193 samples.

After the multispectral data were converted from analog to digital form, gray-scale computer printouts of the area under study were produced. A gray-scale printout was used as a base map on which to indicate the locations of the sampling sites for the 193 surface soil samples.

The remote sensing unit (RSU) or resolution element is the instantaneous field of view of the scanner. At an altitude of 1000 m one resolution element for the University of Michigan airborne scanner covers an area 1.5 meters in diameter on the earth's surface. Using multispectral scanner data, the average radiance value from four RSU's (2 x 2) was obtained for the address or location representing each of the 193 samples. Analytical and m multispectral data representing the sampling sites were employed to train the computer. For this study energy measurements were obtained in 13 wavelength bands. The orange portion of the visible spectrum (0.58-0.62 μm) used in analyzing August and September data to cluster maize into different spectral categories.

The clustering technique is useful for establishing spectral categories. In this study the average radiance data for the 4 RSU's representing each of the 193 samples (4 RSU's per sample) were sorted into an array from the lowest relative reflectance to the highest relative reflectance. Then the data in histogram form (Figure 3) were examined to see if there were groups of sample values clustered around specific ranges of relative radiance. Class boundaries were then established on the basis of clustering within different ranges of relative radiance.

The computer was trained with the clustering technique to recognize specific surface feature categories and then instructed to classify all data within the test area. Although single channels were employed to establish the class boundaries, a combination of 6, 12, and 13 channels was used in the computer classification of data from each scanner mission (Table 2).

RESULTS AND DISCUSSION

Multispectral scanner data and automatic pattern recognition techniques can be used very effectively to observe and follow the changes which occur in quantity and quality of crop cover as the growing season advances.

Panchromatic aerial photography, obtained early in May 1970, records the vivid differences in the surface soils of the 40-hectare test field which had been plowed in preparation for seeding to maize (Fig. 2). The darker soils along the left side of the photograph are Ragsdale silty clay (Typic Argiaquoll) and Brookston silty clay loam soils (Typic Argiaquoll), poorly and very poorly drained respectively. On the opposite side of the field is a large area of Brookston silty clay loam. The light colored silt loam soils through the center of the photograph belong to the well-drained Reesevill series (Aeric Ochraqualf). Other series in intermediate zones are Crosby (Aeric Ochraqualf), Toronto (Udollic Ochraqualf), and Celina (Acquic Hapludalf).

Multispectral data obtained on May 6, 1970, were used to produce the computer printout displaying the soil patterns (Fig. 4). Although the rate of digitization resulted in a somewhat elongated image of the test field,

the computer-produced patterns, representing seven spectrally separable categories, have a striking similarity to the soil patterns in the aerial photograph (Fig. 2).

Since these analyses were made with uncalibrated data, absolute radiance values cannot be reported. Only relative radiance or percentage reflectance and reflectance ratio values are discussed in this paper.

Relative reflectance values of bare soils obtained in thirteen different spectral bands, ranging from 0.40 to 2.60 micrometers, reveal that soil reflectance varies significantly in different portions of the spectrum. The striking feature of soil spectra is the high absorbance in the reflective infrared and the low absorbance in the visible portion of the spectrum. The average reflectance for all soils included in this study, regardless of color or type, was 73.68% for the visible region (0.4-0.72 μm) and only 26.32% for the reflective infrared region (0.72-2.6 μm). The upper portion of the reflective infrared (1.0-2.6 μm) gave an average reflectance value which equalled only 12.25% of the total reflected energy. These percentages were determined with the following equation:

$$R = \frac{r_1}{r_2} \times 100$$

where R is the percent relative reflectance of a certain portion of the spectrum (0.4-2.6 μm),

r_1 is the average relative reflectance from that portion of the spectrum for which a percentage value is desired, and

r_2 is the average relative reflectance from the entire reflective region (0.4-2.6 μm).

At the time of the June 30 multispectral scanner mission, maize was growing over the entire test field. The west one-third of the field, having been planted earlier than the remainder of the field, had an estimated 30 to 40% ground cover. Ground cover on the east two-thirds approximated 10 to 20%. The same clustering method used with the May data was used to produce the computer printout with June 30 data (Fig. 5). A comparison of the spectral patterns from the May 6 (7 spectral categories) and June 30 (10 spectral categories) data reveals a general similarity in spectral patterns of the surface features. Seemingly the soil spectral boundaries are less distinct in the June data in the west portion of the field where the percentage of ground cover or maize canopy was greater than for the remainder of the field.

Leaf morphology and pigment content greatly affect the absorbance of incident electromagnetic radiation by the

green plant. It has long been known that the chlorophylls absorb a great deal more of the blue and red than of other regions of the visible spectrum (7,8,10). Most of the reflected energy is in the green spectral region.

Multispectral data for the June 30 mission, even when uncalibrated, show that the relative intensity of reflected radiation decreased in the visible region and increased in the reflective infrared region from similar measurements for the May flight. This indicates that in its measurement of radiating energy, the scanner intergrates the input of radiating energy from exposed bare soil with that from the young maize plants.

Following the June 30 scanner mission, six weeks elapsed before the next multispectral data were obtained. Significant changes had occurred in the percent ground cover and in plant morphology. The computer printout (Fig. 6) illustrates the effect of the soil background on the energy reflected by maize. Absorbance of energy is substantially higher with maize plants on darker soils than with maize on lighter colored soils. Dark soils reflect solar energy in lesser quantities than do light colored soils.

At the time of the August 11 scanner mission all of the maize had tasseled. When the scanner was receiving energy measurements at nadir, it was receiving radiation from both plants and soils. The estimated percent ground cover was 75 to 85. However, when the scanning mirror was receiving reflected energy at a few degrees off nadir, it can be assumed that essentially 100% of the reflected energy was being reflected from plants.

A comparison of the spectral patterns from the August 11 data (Fig. 6) with the soil patterns from the May 6 flight (Fig. 4) reveals that some of the gross soil patterns are showing through the corn canopy.

The final scanner data used in this research were collected on September 5. The most striking feature of the spectral pattern generated from this data (Fig. 7) is the dark north-south strip in the left third of the computer printout. This area represents a lower relative reflectance from a strip of maize in which the chlorophyll had deteriorated much more rapidly than in other areas of the field. This breakdown resulted from infection of corn blight or natural senescence in this particular strip.

Examination of the changes in reflectance which occur with increasing green canopy led to the use of a ratio between visible reflectance and infrared reflectance to

quantify these changes. Although these calculations were made with uncalibrated scanner data, the results proved to be useful in interpreting the changes in spectral patterns. The following equations were used:

$$A = \frac{V}{I} \tag{2}$$

where A is the ratio between relative visible reflectance and relative infrared reflectance,

V is the relative reflectance in the visible spectrum (0.4-0.72 μm), and

I is the relative reflectance in the near infrared (0.72-2.6 μm);

and

$$A_1 = \frac{V_1}{I_1} \tag{3}$$

where A_1 is the ratio between the relative reflectance of a specific portion of the visible spectrum and the relative reflectance of a specific portion of the reflective infrared,

V_1 is the relative reflectance from the 0.58-0.62 μm spectral band, and

I_1 is the relative reflectance from the 0.80-1.00 μm spectral band.

Since nonvegetated soils absorb relatively little energy in the visible spectrum and relatively more in the reflective infrared spectrum, the highest ratio values were obtained with the May data (Table 3). For the late maize the ratio values decreased with each succeeding scanner flight. This supports the phenomenon which occur as the green canopy absorbs more of the visible and reflects more of the infrared energy. There seems to be some discrepancy in the ratio values for the early maize area, especially on the dark soils. The ratio for June 30 was 0.97. This increased to 1.06 on August 11 and 1.09 on September 5. One possible explanation is that the early maize suffered much leaf damage from the Southern corn leaf blight. Another explanation could be the use of uncalibrated scanner data.

The most severe chlorophyll deterioration occurred in the depressional areas where the dark soils are located. As chlorophyll breakdown occurs and the plants lose moisture, the energy absorption in the visible wavelengths will recede and reflectance in the infrared will decrease.

CONCLUSIONS

Use of multispectral scanner data obtained from aircraft and eventually from space platforms for observing and characterizing soils and crop canopies appears promising. Multispectral measurements of vegetative cover may reveal certain properties of the soils below. The ratio between relative reflectance in the visible spectrum and relative reflectance in the infrared spectrum may be used to characterize quantity and quality of vegetative cover.

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TABLE 1. MULTISPECTRAL SCANNER FLIGHTS

Date	Altitude	Time of Day	Condition of Field
May 6	915 m	10:25 a.m.	Field plowed, soil without cover
June 30	915 m	10:30 a.m.	15-45% ground cover, maize
Aug. 11	1520 m	2:50 p.m.	90% or more ground cover, maize
Sept. 5	915 m	11:20 a.m.	90% or more ground cover, maize

TABLE 2. SPECTRAL BANDS USED IN ANALYSIS OF SCANNER DATA.

Spectral bands (micrometers)	May 6	June 30	August 11	Sept. 5
0.40-0.44	x	x	x	x
0.46-0.48		x	x	x
0.50-0.52	x	x	x	x
0.52-0.55		x	x	x
0.55-0.58	x	x	x	x
0.58-0.62	x	x	x	x
0.62-0.66		x	x	x
0.66-0.72	x	x	x	x
0.72-0.80		x	x	x
0.80-1.00	x	x	x	x
1.00-1.40		x	x	x
1.50-1.80		x	x	x
2.00-2.60				x

TABLE 3. EFFECT OF STAGE OF MATURITY OF MAIZE AND SOIL ON THE RATIO BETWEEN VISIBLE AND INFRARED REFLECTANCE.

$$\text{Ratio} = \frac{\text{relative reflectance } (0.58\text{-}0.62\ \mu m)^{*}}{\text{relative reflectance } (0.80\text{-}1.00\ \mu m)}$$

	Early Maize Soil Color		Late Maize Soil Color	
	Light	Dark	Light	Dark
May 6	1.54	1.49	1.54	1.49
June 30	1.16	0.97	1.32	1.20
August 11	1.03	1.06	1.00	0.98
September 5	1.04	1.09	0.81	0.85

Calculated with uncalibrated scanner data.

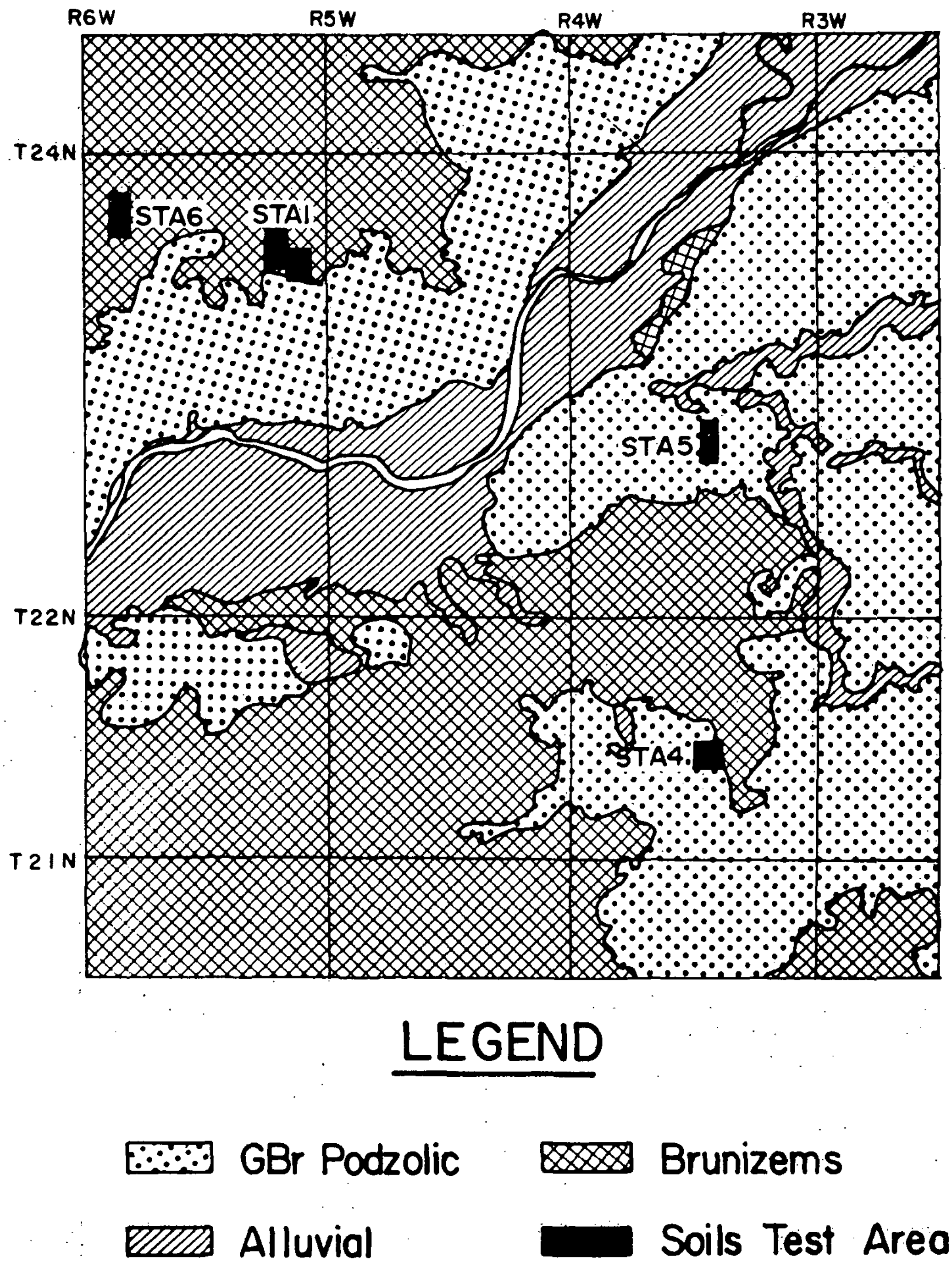

Figure 1. Great soil groups of Tippecanoe County, Indiana.

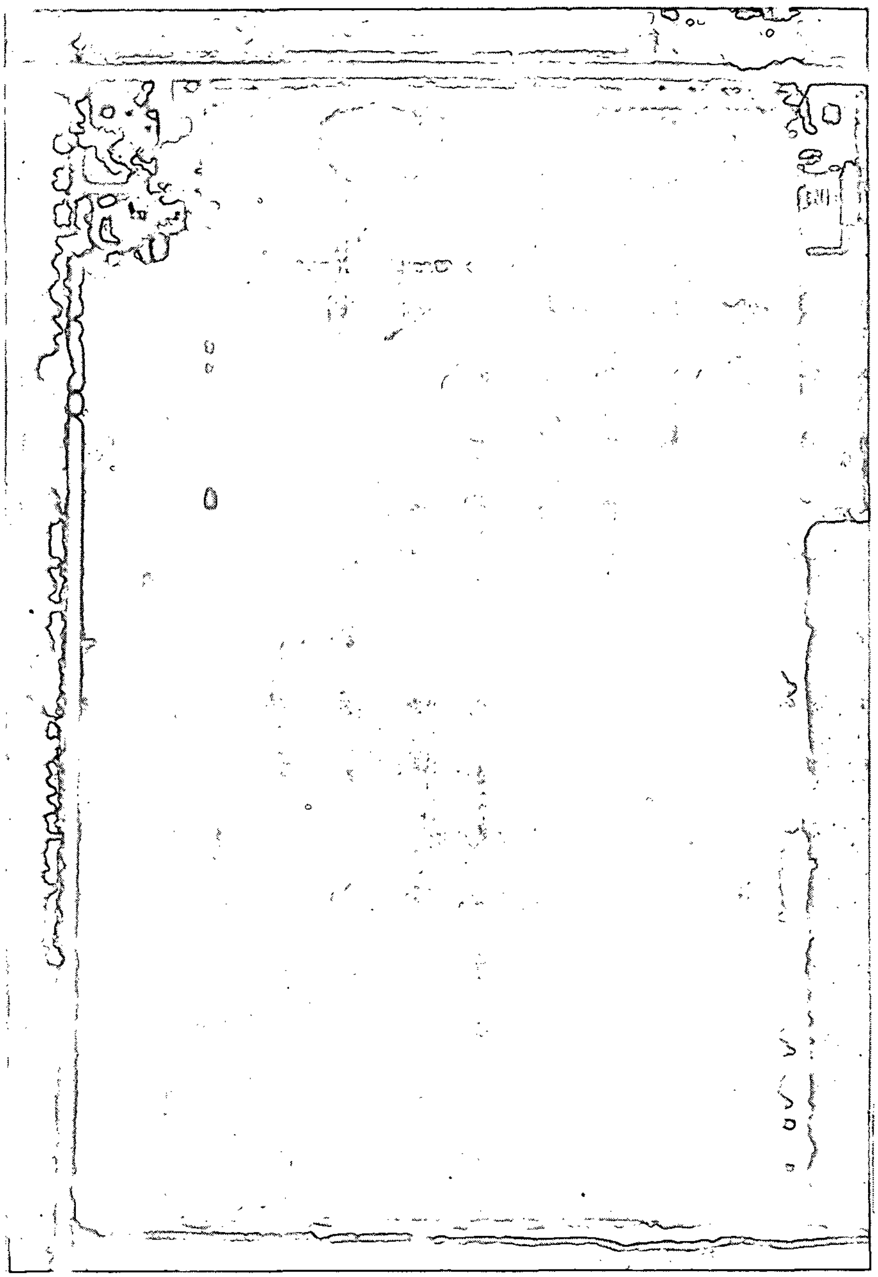

Figure 2. Aerial photograph of Soil Test Area 5.

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HISTOGRAM OF CLASSES
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      42.000    **
      43.000    **
      44.000    ***
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      82.000    **
      83.000    *
      84.000    ***
      87.000    ***
      88.000    ****
      89.000    *
      91.000    ****
      92.000    **
      93.000    ***
      94.000    ****
      96.000    *
/E
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Figure 3. Histogram of the array of relative reflectance of the 0.58-0.62 μm spectral band, May 6, 1970.

Figure 4. Multispectral patterns of soils from scanner data obtained on May 6, 1970.

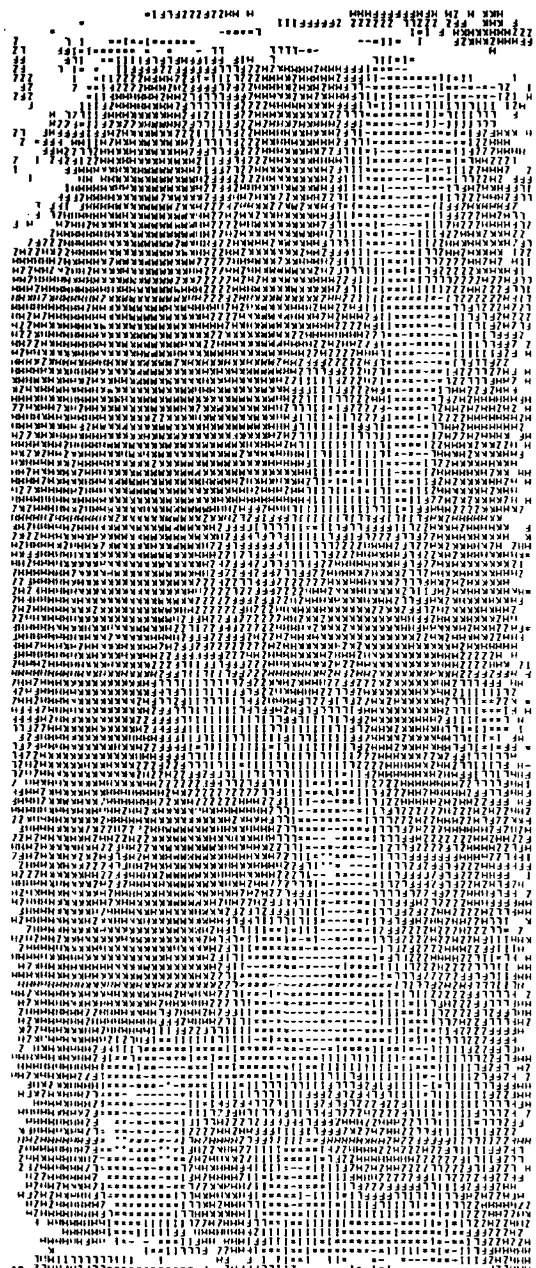

Figure 5. Surface spectral patterns obtained from June 30 scanner data over Soil Test Area 5.

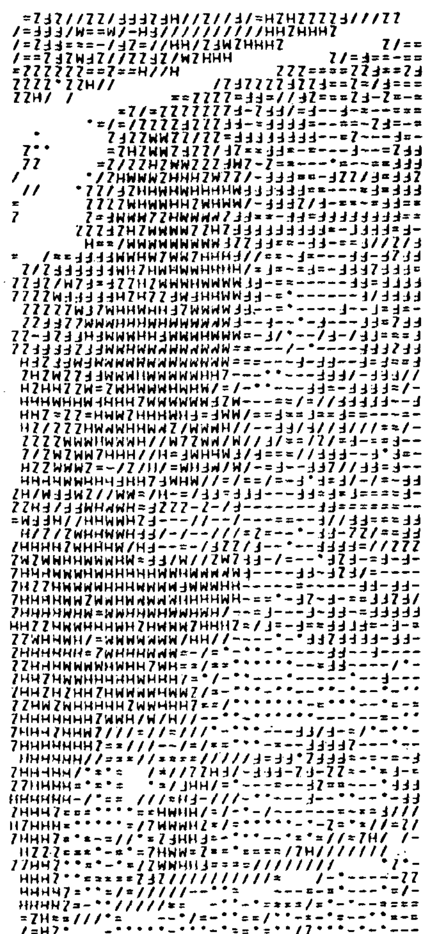

Figure 6. Spectral patterns from August 11 scanner data obtained over Soil Test Area 5.

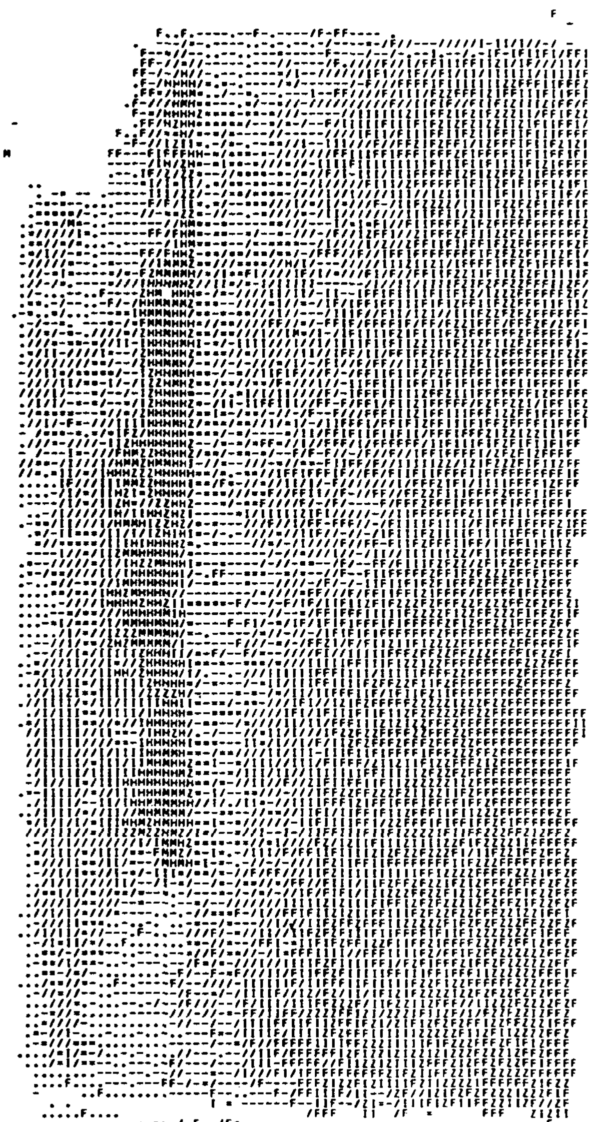

Figure 7. Spectral patterns from September 5 scanner data obtained over Soil Test Area 5.